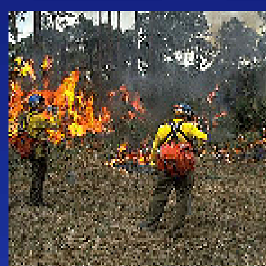
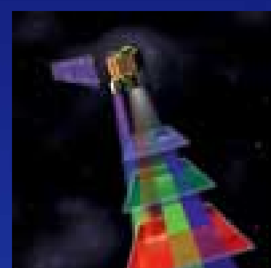
ECOLOGICAL FORECASTING



AGENDA FOR THE FUTURE

CENR

Committee on Environment and Natural Resources
Subcommittee on Ecological Systems

Ecological Forecasting: Agenda for the Future

It Begins with a Vision

We are pleased to present our vision of ecological forecasting today — and ask you to consider what it could mean to our nation tomorrow. Today, at the beginning of the 21st century, the science community is poised to enhance the way we anticipate and manage environmental risk and capitalize on resource opportunities. Technological innovations of the last decade in computer science and quantitative analytical capabilities, information and sensing technologies, genomics, systematic biology, and nanotechnology make it possible to undertake sophisticated ecological forecasting in ways that were not feasible only a few years ago.

U.S. agriculture is vitally important to the U.S. economy, as well as the health and well-being of U.S. citizens and those of many nations around the world.

The stakes in preserving our ecosystems and the fragile webs that bind them are enormous.

What is Ecological Forecasting?

The stakes in preserving our ecosystems – and the fragile webs that bind them — are enormous. Whether we realize it or not, the health of the U.S. economy is inextricably linked to the health of our nation's ecosystems, and the goods and services those ecosystems deliver.

Consider a sampling of the goods. Agricultural ecosystems provide over $200 billion annually. Marine ecosystems provide almost $4 billion in fisheries alone. Worldwide, temperate forests provide raw materials valued at more than $890 billion.

However, ecosystems do more than furnish food and fiber. Ecosystem "services" provide — among many other things — clean air and water for every citizen, and the detoxification and decomposition of wastes, the pollination of crops and natural vegetation, drought and flood control, and recreational opportunities.

Healthy ecosystems contribute mightily to the U.S. recreation and tourism industries.

To sustain our precious and extraordinarily valuable goods and services, we have to understand how ecosystems function and interact and, perhaps most importantly, forecast how they will be affected by change.

Ecological forecasts predict the effects of biological, chemical, physical, and human-induced changes on ecosystems and their components. Ecological forecasting does *not* guarantee what is to come; instead, it offers an educated estimation of what is likely to occur.

Such forecasts, answer "What will happen if…" questions tied to these changes. Short-term forecasts are similar to those done for weather prediction. Forecasting large-scale, long-term changes to ecosystems is more akin to macroeconomic forecasts that build from expert judgment, analysis, and assessment, in addition to numerical simulation and prediction. Forecasting such broad-based, long-term changes is particularly important because some of the most severe and long-lasting effects on ecosystems may result from chronic influences that are subtle over short time frames.

Forecasting the ecological impacts of change supports the management of ecosystems, especially those at risk, so we can ensure long-term delivery of goods and services, as well as decrease negative impacts from certain events — and minimize harm to people and the economy. The prediction and improved management of wildfires is just one example.

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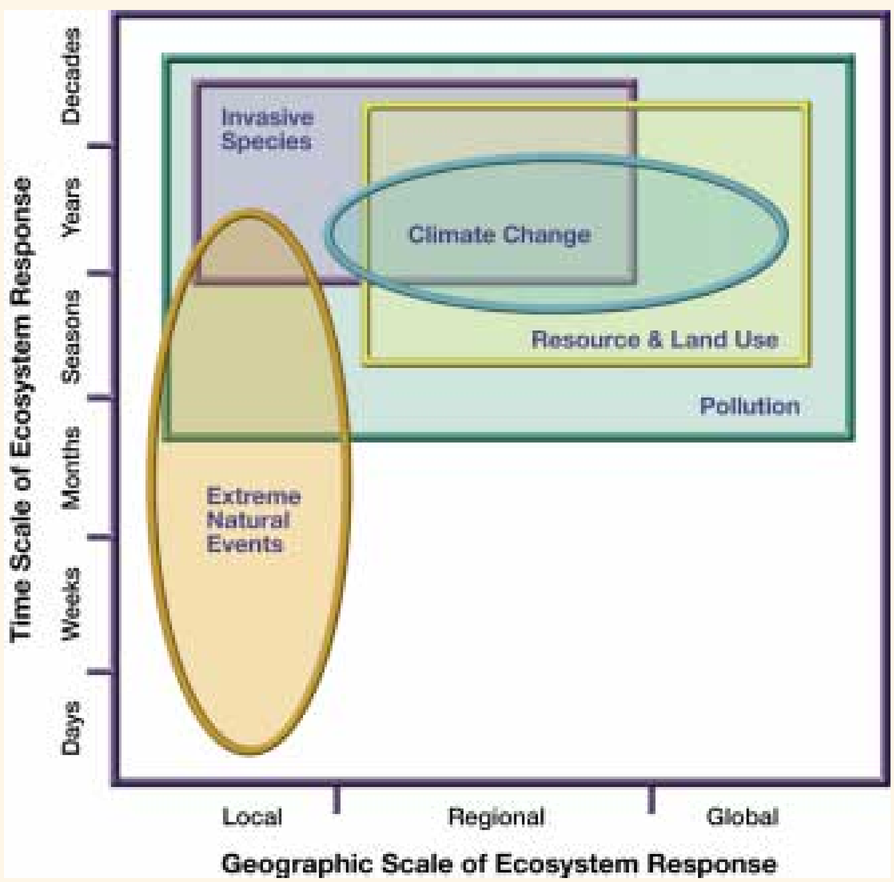


The key causes of ecological change (pollution, extreme natural events, invasive species, atmospheric and climate change, and land and resource use) play out on a wide range of time and space scales, from years to decades and from localities to the globe.

What are the Benefits of Ecological Forecasts?

Ecological forecasts help resource managers (such as superintendents at National Parks) better understand their options and the likely effects of a wide variety of management decisions. Ecological forecasts, in essence, help managers "know" the future.

Ecological forecasts help focus discussions at the science/policy interface. When discussions are focused around the need for and confidence in specific forecasts, it helps identify data, information, and predictions that will have the most profound economic, environmental, and policy implications.

Land managers make crucial decisions that can affect the well-being of ecosystems for decades to come.

Ecological forecasts help science managers set research, monitoring, modeling, and assessment priorities.

Finally, ecological forecasts will help the general public since we are all affected by ecosystem health and stability, perhaps most directly through the economy's health — but also, for instance, through our ongoing need for reliable water supplies and flood protection, as well as our interest in enjoying the beauty and wonder of ecosystems by watching wildlife.

Watching and enjoying wildlife is an activity we can all enjoy when our nation has healthy ecosystems.

The Need for Ecological Forecasts

The five causes of ecosystem change provide a framework for ecological forecasting needs.

Extreme Natural Events — Such events include fire, floods, droughts, hurricanes, and windstorms. While extreme natural events are largely outside the control of natural resource managers, the ability to predict their occurrence and ecosystem effects, as well as their interactions with other causes of change, are important in planning management and response activities.

Climate Change – These changes affect all ecosystems. As certainty about the likelihood and magnitude of climate change increases, the need for resource managers and policy makers to plan to minimize impacts on ecosystems, species, and ecological goods and services becomes more urgent. Current needs include forecasts of climate impacts on ecological services to human populations, particularly the availability of clean water.

Land and Resource Use – All changes to ecosystems in the coming decades will take place in the context of ongoing changes in land and resource use. Forecasts of the far-reaching implications of these shifts on ecosystems, and their impacts on society, are needed. Current needs include forecasts of changes in the health and productivity of natural and managed ecosystems that are critical in providing food and fiber to the U.S. economy — especially agricultural, forest, and rangeland ecosystems.

Pollution – Concerns about the presence of potentially harmful chemicals and excess nutrients in the environment remain a top concern. Current needs include forecasts of the effects of activities at landscape scales (for example, agricultural production, forest harvest, atmospheric transport) on freshwater and marine ecosystems; and forecasts of the effects that pollution has on human health.

"One of the most pressing challenges that the United States—and indeed, the world—will face in the next few decades is how to alleviate the growing stress that human activities are placing on the environment. The consequences are just too great to ignore... Yet, there is reason to have hope for the future. Advances in computing power and molecular biology are among the tremendous increases in scientific capability that are helping researchers gain a better understanding of these problems."

—Thomas Graedel
Yale University School of Forestry and Environmental Studies

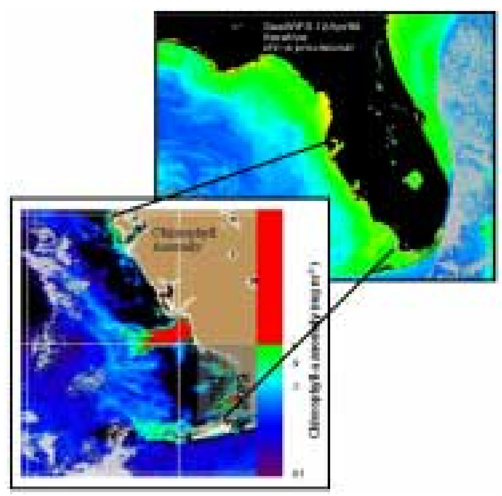
Invasive Species – Invasive species are species alien to our ecosystems and introduced from their natural range by intentional or unintentional human activities. Invasive species exist in nearly all U.S. ecosystems. These species pose serious threats to the integrity of our nation's landscapes, biodiversity, and ecosystems *and* annually cost billions of dollars to control. Controlling their spread requires timely and accurate scientific information on the species posing the threat. Current needs include forecasts of the spread and ecological effects of already-introduced species and of new and emerging diseases of fish, wildlife, plants, and humans.

The Asian longhorned beetle (Anoplophora glabripennis*) poses a serious threat to hardwood trees in the United States. The beetle feeds deep within the tree, blocking water and sap movement, until it eventually kills the tree. If not controlled, the beetle can become a major pest of forests and backyards, and have a significant impact on the lumber, maple syrup, nursery, commercial fruit, and tourism industries. For invasive species already established, such as the Asian longhorned beetle, ecological forecasting can combine information on the basic biology of the organism (its preferred host trees, timing of development, population growth rate, susceptibility to natural enemies) with patterns of human activities that influence dispersal (for instance, urban/suburban land use patterns, forest management practices) to model the likely direction and rate of spread.*

Interactive Effects – Ecosystems throughout the United States will be subject to many or all of the aforementioned causes of ecological change. For example, the success of a particular invasive species may be determined by a recent extreme natural event (perhaps a fire), the evolving climate (for instance, changes in precipitation and temperature patterns), current land and resource use (is it managed or unmanaged?), and the chemical properties of the environment being invaded (considering the effects of possible pollutants). In short, our vision of ecological forecasting today includes the goal to hasten the day we can forecast the ecological effects of multiple, interacting sources of stress.

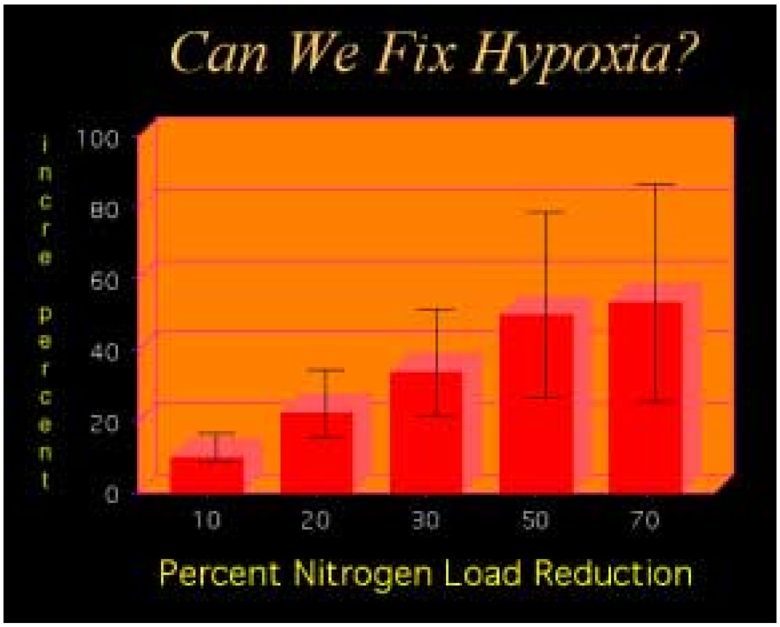
Bringing the Future into Focus

Harmful Algal Blooms (HABs) – lethal growths of algae — are increasing in the United States, affecting coastal resources, local economies, and public health in almost every coastal state. They occur naturally in U.S. waters, but appear to be increasing in frequency, duration, and severity. HAB species restrict harvests of fish, divert public funds to health and environmental monitoring programs, depress recreational and tourist industries, and can cause illness and even death in those who consume products from the sea. Detection, monitoring, and forecasting of HABs would help reduce these impacts by identifying where blooms are and allow early warning of shellfish and beach closures. Currently we can predict where a HAB may come ashore once it has started, but further research is needed to predict when and where a bloom will develop.



Combining this satellite imagery with information on ocean circulation and atmospheric conditions enables forecasts of blooms off Florida's west coast. State officials used these forecasts to track the bloom and warn the public.

Hypoxia — Scientists have undertaken a broad-scale assessment of the causes and consequences of oxygen-depletion (hypoxia) in the Gulf of Mexico. The main concern is that most aquatic species cannot survive at low oxygen levels. This phenomenon, therefore, is a serious challenge to scientists — and many others — since it takes place in the middle of an important commercial and recreational fishery and could threaten the economy of this region of the Gulf.



The extent and duration of hypoxia appears to be increasing in the Gulf of Mexico and elsewhere. Forecasts, like the one shown here, were critical for reaching a Federal/State/Tribal agreement to take action within the Mississippi River Basin to reduce the size of the hypoxic zone.

Hantaviruses are diseases carried by rodents, especially the deer mouse. People become infected by exposure to rodent droppings. These viruses are potentially deadly, requiring immediate medical care once symptoms appear. Until recently, diseases caused by hantaviruses were thought to be restricted to Europe and Asia. But outbreaks in the United States in 1993 proved otherwise. An understanding of the relationship between climate change, ecology, and natural pathogens may enable the development of predictive models for human infection and allow forecasts of human risk. In 1997, we were able to use the technologies of the day and predict that year's outbreak.

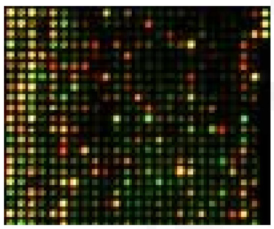
Rodents such as the deer mouse can carry hantaviruses.

New Era Possible Through New Technologies

Today, ecological forecasting is a reality. But while there has been notable progress, the promise of this maturing field lies on the horizon.

More to the point, a variety of recent developments have converged to offer us an historic opportunity to dramatically accelerate progress in the way we make ecological forecasts. Technological advances, particularly in computer science, telecommunications, remote sensing, genomics, and nanotechnology, offer us the very real chance to raise ecological forecasting to new and unprecedented levels. The ecological science community is in a new era in which accurate forecasting of ecological conditions and opportunities can become commonplace if we can bring to bear the new tools, monitoring systems, and research needed to develop such forecasts.

The mass storage capabilities these systems embody could prove invaluable to ecological forecasters.



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Smart dust packs the power of a PC into a mote of "dust."

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For example, the National Aeronautics and Space Administration's Earth Observing System (EOS) collects data for use in measuring Earth system changes. Over the next 15 years, EOS will collect data on an unprecedented scale via a series of satellites and field experiments. A network of data centers, such as the U.S. Geological Survey's EOS Data Center, will assemble, archive, and distribute enormous amounts of EOS data. Currently, robotic mass storage systems are managing hundreds of terabytes of information (a byte is the memory space needed to store 1 character, a gigabyte is 1 billion bytes, and a terabyte is 1 trillion bytes). But over the next decade, thousands of times that amount will be collected and made available to individuals working around the world.

Other innovations have grown out of work over the past decade on various genomes. A genome consists of the complete complement of genes in an organism; in other words, it is the genetic instruction set or blueprint for that species. Today we have finished identifying and placing in order all the genes from several model organisms (for example, *Arabidopsis*, from the mustard family) and have a rough draft of the human genome. Gene/protein chips (an innovation from the fields of biotechnology and nanotechnology) are offering unprecedented opportunities to measure, monitor, and understand the complex structures and activities of living systems. This technology lets researchers monitor biological genetic diversity on a single chip so that scientists can have a better picture of the interactions among thousands of genes simultaneously, and discover which genes are affected by various environmental changes.

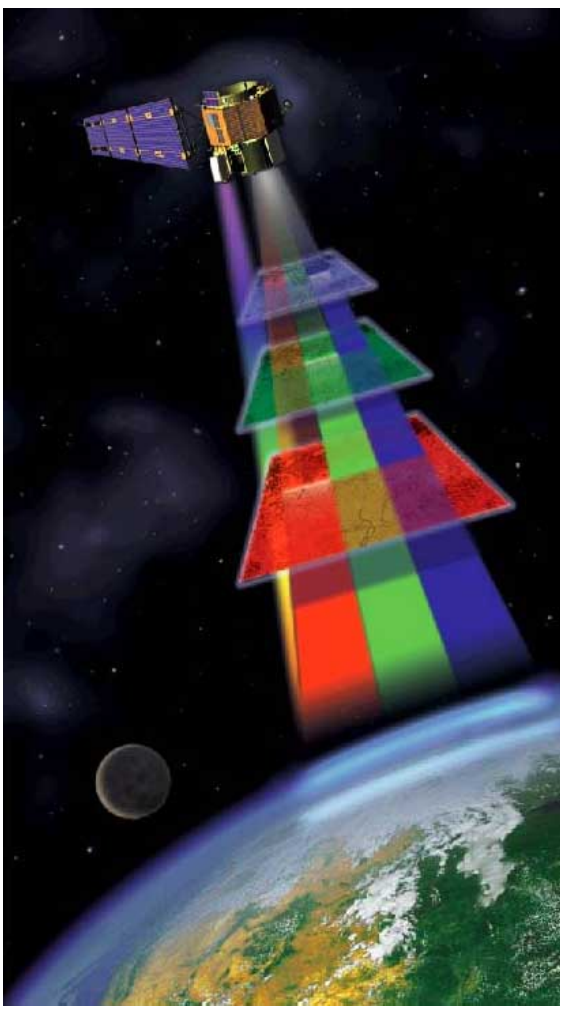
Another recent innovation holds great promise for application(s) in the world of ecological forecasting, even though its name might inspire raised eyebrows. "Smart dust" features the smallest computerized sensors designed to communicate. These tiny sensors seem like particles of dust and can be scattered — typically, from planes — to send back information as they float to earth. They are light enough that air currents can keep them aloft for lengthy periods of time. Applications already envisioned for this dust with a difference include checking the weather inside storms, warning jetliners of air turbulence, and detecting chemical weapons. Future "smart dust" research is aimed at imbuing significantly smaller particles with even greater communications capabilities and using these tiny sensors to communicate the dynamics of some of the smallest components of ecosystems.

At the same time, while innovative technologies can greatly strengthen our capabilities, ecological forecasting is broader than computational tools and models. It must also include gathering expert opinion on the many factors affecting our ecosystems, as well as identifying shortcomings in our current scientific understanding. This process, in turn, can help set the research agenda.

Framing the Agenda

The science agenda for ecological forecasting is rooted in three themes:

Understand Ecosystem Composition, Structure, and Functioning. While advances have been made in this area, a new approach is needed that responds to recommendations of the National Academy of Sciences (*Grand Challenges in the Environmental Sciences*, *Science and the Endangered Species Act, Rediscovering Geography, Priorities for Coastal Ecosystem Science*), the President's Committee of Advisors on Science and Technology (PCAST [*Teaming with Life: Investing in Science to Understand and Use America's Living Capital*]), and the National Science Board (*Environmental Science and Engineering in the 21st Century)*. These efforts focus on the need to enhance the scientific base required for ecological forecasting.



A new generation of earth observing satellites has ushered in the next generation of remote sensing technologies offering significantly greater coverage, resolution, and range of measurement abilities than ever before. These technologies are opening new ecological observation windows – and new ecological forecasting possibilities.

Monitor Ecosystem Status and Trends, and Make Complex Data Available. Ecological forecasts cannot be produced without reliable information about the current and historical condition of ecosystems. Likewise, the success of decisions made in response to specific forecasts cannot be evaluated without ongoing monitoring of change. Rapid advances in remote sensing and *in situ* sensing ("in the actual place"; contrasted with "remote") provide an unprecedented opportunity to provide these data. However, new observation and data management technologies are needed to deal with gathering complex biological and chemical data, and making them available.

PCAST spoke of the need to support development of a National Biological Information Infrastructure, a Web-based system for accessing and integrating biodiversity and ecosystem information.

Develop and Improve Prediction and Interpretation Tools. A central challenge for ecological forecasting is to develop advanced tools for translating the rapidly increasing ecological knowledge base into information needed by decision makers. The combination of complex interactions among a large number of components with the variable nature of ecosystems and their driving forces, makes the development of such tools a significant challenge.

Collaboration is the Key

The basis of scientific predictions is good data and information and a solid understanding of natural processes. Strong collaboration among Federal agencies, with the academic community and with the private sector, is essential for ensuring development of ecological forecasting capabilities.

Soaring Opportunities

Now, at the beginning of the twenty-first century, we are poised to capitalize on soaring opportunities as we significantly change the way we anticipate and manage ecological risk.

Accomplishing this vision will be a challenge, but it is not beyond our reach. It will unfold as its assumptions and ideas are tested. With that in mind, our agenda is purposeful — but flexible. We invite you to help us shape it.

For More Information

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